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AEC-NASA TECH BRIEF

Retention of Ductility in High-Strength Steels

The problem:

To increase the yield strength of alloy steel while maintaining a relatively high degree of ductility. In the normal heat-treatment of steel, strength is sacrificed for retention of ductility. High degrees of both strength and toughness are seemingly incompatible. Generally, the strongest steels have tended to be brittle; ductile steels, weak.

The solution:

A process to produce high-strength alloy steel, with retention of ductility, includes a series of steps: tempering, application of stress at an elevated temperature, cooling, and subsequent tempering. The steel is strained at temperatures between 150° and 900°F, cooled, and then retempered. The strain aging at elevated temperature substantially increases the yield strength (sometimes by as much as 25%) and favorably shapes the stress-strain curve for good mechanical properties. In general, steels whose tensile strengths exceed 200,000 psi and have 10% ductility are classified as high-strength steels.

How it's done:

The process is applicable to quenched and tempered steels having fine-grained martensitic microstructures. Stress is applied to the steel for a controlled time, to effect a plastic strain between about 0.25 and 5%, while the steel is maintained at an elevated temperature below that at which precipitates would coalesce. The steel is then cooled and may subsequently be tempered if necessary.

The process conditions differ in detail for each alloy, but readily can be determined experimentally. Essentially, these five parameters are varied for optimum results: (1) pretempering temperature, (2) amount of strain, (3) strain rate, (4) temperature during strain, and (5) temperature of subsequent tempering.

The pretempering and final tempering are optional steps if the ductility and toughness of the steel are sufficient without tempering. The pretempering temperature is generally maintained at about 600°F, the temperature at which iron carbides form, but in any case below the temperature of about 900°F at which alloy carbides form. Thus the subsequent strain aging at an elevated temperature nucleates the alloy carbides that are still in solution.

The amount of strain has an upper limit determined by the plastic limit of the steel; it is about 5% for certain steels. The minimum strain that may be employed is the amount sufficient to form dislocations for nucleation sites to occur; it is about 0.25% for certain other steels. The three different strain rates used, 1.35×10^{-3}/sec, 1.35×10^{-4}/sec, and 1.35×10^{-5}/sec, showed minimal difference in effect on product strength.

The temperature of the steel during the strain substantially affects the final properties; it may range from room temperature to about 900°F. The straining temperature is generally maintained below the temperature of the final tempering. Appropriate selection of the steps and process conditions within these general limits leads to the desired combination of strength and ductility.

Notes:

1. This innovation may interest all industries (such as aircraft and transportation) requiring high strength-to-weight ratios.

(continued overleaf)

2. Inquiries concerning this innovation may be directed to:

   Office of Industrial Cooperation
   Argonne National Laboratory
   9700 South Cass Avenue
   Argonne, Illinois 60439
   Reference: B69-10616

   Source: V. F. Zackay and E. R. Parker of Lawrence Radiation Laboratory under contract to Argonne National Laboratory (ARG-10497)

Patent status:

Inquiries concerning rights to commercial use of this innovation may be made to:

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